TETA TO - 0028
November 8, 1994
Michael R. O'Connell

# TEST EFFECTIVENESS TREND OBSERVATION

## Spacecraft Level Sine Vibration Testing Effectiveness Criteria

### CONCLUSION:

A deterministic set of criteria for when to, and when not to, perform spacecraft system sine vibration testing has been developed. This criteria evaluates the benefit of the sine test, based on its effectiveness as a workmanship test and for qualification of hardware and secondary structure for the low to mid frequency launch mechanically transmitted vibration environments. The sine testing has been rated as an effective low frequency vibration verification and qualification method for complex spacecraft like Galileo and Mars Observer (the MO sine vibration test was compromised). Sine vibration testing is rated as moderately effective in verifying less complex spacecraft like the recent Mars Pathfinder and Magellan spacecraft. Sine vibration testing has been deleted for spacecraft in this category, in the face of cost and schedule constrains, with less risk than would be assumed for the traditional JPL planetary spacecraft.

### DISCUSSION:

A criteria has been developed to guide the decision process for the use of system level sine vibration tests, Attachments 1 and 2. The value of the sine test is evaluated based on its effectiveness as a workmanship test of mechanisms, deployables, cables, connectors, etc. and its effectiveness for qualification of these hardware and secondary structure for the low to mid frequency launch mechanically transmitted vibration environments (primary structure is conventionally qualified by analysis, with supporting modal and static tests). The criteria is weighted towards workmanship, which typically turns out to be the predominant system sine test issue, rather than qualification. The combined issues of hardware sensitivity, extent of verification and the related adequacy of spacecraft responses are also emphasized. The criteria has been used to rank the effectiveness of sine testing on several recent JPL spacecraft, Attachment 2.

Sine testing at the system level is the most expensive and complex to plan, implement, and conduct of all dynamic environmental tests. Since the test inputs must be controlled to not exceed structural design capability, a complex response limited, input notched test method is required. As a result of the requirement to limit test loads to near structural capability and the large force output capability of the shaker system, the sine test has a potential for inadvertent or inappropriate damage to the spacecraft. Actual conduct of the test takes significant schedule time to setup and conduct due to the above test complexity. Automatic force limiting provides a potential approach to simplify the spacecraft sine vibration test and reduce test cost but it has not yet been fully demonstrated on a flight spacecraft.

The reasons for spacecraft sine testing are as follows:

1. Low frequency sensitive items such as mechanisms and cabling are tested for workmanship and design defects better than by other tests.

2. Secondary structure designs not testable by other means can be qualified by this test.

3. To provide Qualification and a workmanship test for sensitive hardware not tested at the assembly level.

Based on the cost, risk and schedule involved in sine testing, the potential risk of not conducting such a test can be assessed based on the following considerations:

1. The spacecraft may have only a limited number of deployable mechanisms or booms that would be effectively tested by sine.

2. The spacecraft may be designed to survive very high loads which provide high design margins over the launch environments.

3. A random vibration test may be used to serve as a workmanship and qualification test (at Protoflight levels).

4. Due to other considerations, the spacecraft may be largely disassembled for shipment to the launch site thus reducing some of the workmanship benefits of the low frequency sine test. Recurrence of workmanship defects is usually prevented by design or procedure changes.

System sine testing results vary among institutions and companies. Statistical studies by some non-JPL sources put sine testing last in test effectiveness rating while other organizations find numerous defects from system sine tests (perhaps due to variances in design practices, assembly processes, assembly testing and inspection procedures). These factors must also be taken into account when determining the value of a system sine test.

Based on the above, the benefit to demonstrated reliability of performing a system sine test may, or may not be, significant enough to override the benefits of using the technical, cost and schedule resources for other testing. The remaining system environmental test program, including a thermal vacuum test, radiated EMC/EMI tests, and an acoustic test, may qualify and workmanship test the spacecraft. The decision to sine test or not to sine test is necessarily a subjective one. However, JPL spacecraft with a average Sine Test Effectiveness rating above 4.0 have all been sine vibration tested by JPL as a full up spacecraft. Projects have accepted the risk of deleting sine vibration testing for less complex spacecraft, with a test effectiveness rating below 4.0, where a moderate test effectiveness did not outweigh cost and schedule constraints.

## Attachment 1

## Decision Process for Use of System Level Sine Tests

| | | TEST EFFECTIVENESS | | | |
|---|---|---|---|---|---|
| **Purpose** | **Cat** | **Criteria** | **Discussion** | **Rating (1-5)** | **Comments** |
| Workmanship testing of mechanisms, deployables, cables, connectors, etc. as an assembled spacecraft in the low- to mid-frequency range | A1 | Potentially susceptible hardware | What is the extent/ criticality of hardware for which a sine test does/could verify the adequacy of workmanship? | | |
| | A2 | Overlap with other tests. | Verifies hardware workmanship; verification not provided by other tests (consider what is left out if a sine test isn't performed)? | | |
| | A3 | S/C responses adequacy | To what extent are/ could adequate response levels be achieved to validate workmanship; i.e., will primary structure load limiting requirements compromise the workmanship verification? | | |
| | A4 | Maintaining system integrity. | To what extent will the tested system remain intact? Examples; ship and shoot would rate a 5, disassemble major subsystems 3, complete disassembly 1. | | |
| | A5 | Post test evaluation | To what extent can workmanship defects precipitated by the sine test be detected by post test inspection or performance evaluation? | | |
| | A6 | Facility Workmanship | Qualitative assessment of Contractor/NASA Center Workmanship, Large # of past failures | | |

| Purpose | Cat | TEST EFFECTIVENESS Criteria | Discussion | Rating (1-5) | Comments |
|---|---|---|---|---|---|
| Qualification of mechanisms, deployables, cables, connectors, secondary structure, etc. for the low- to mid-frequency mechanically transmitted launch vibration (transient, random or periodic)? | B1 | Potentially susceptible hardware | What is the extent/ criticality of hardware for which a sine test does/could | | |
| | B2 | Qualification to other requirements | Verifies hardware qualification for the low to mid frequency vibration environments; verification not provided by other tests (consider what is left out if a sine test isn't performed)? | | |
| | B3 | Post test evaluation. | To what extent can hardware failures induced by the sine test be detected by post test inspection or performance evaluation? | | |
| | B4 | Facility Design practices | Qualitative assessment of Contractor/NASA Center Design practices, Large # of past failures | | |

Sine test effectiveness ratings:

5- high effectiveness
4- good effectiveness
3- moderate effectiveness
4-
2- limited effectiveness
1- ineffective

# Attachment 2

## Sine Test Effectiveness Rating

| CRITERIA | Pathfinder | MGN | CASSINI | GLL | MO | TOPEX |
|---|---|---|---|---|---|---|
| A1 | 3 | 2 | 5 | 5 | 4 | 4 |
| A2 | 2* | 3 | 1** | 5 | 4 | 4 |
| A3 | 5 | 4 | 4 | 5 | 4 | 4 |
| A4 | 4 | 4 | 4 | 4 | 4 | 4 |
| A5 | 4 | 4 | 4 | 4 | 4 | 4 |
| A6 | 2 | 2 | 2 | 2 | 4 | 4 |
| **Sub Total** | **20** | **19** | **20** | **25** | **24** | **24** |
| B1 | 3 | 3 | 5 | 5 | 5 | 4 |
| B2 | 2* | 4 | 3 | 5 | 5 | 4 |
| B3 | 4 | 4 | 4 | 4 | 4 | 4 |
| B4 | 2 | 2 | 2 | 2 | 4 | 4 |
| **Sub Total** | **11** | **13** | **14** | **16** | **18** | **16** |
| Overall Total | 31 | 32 | 34 | 41 | 42 | 40 |
| Criteria Average | 3.1 | 3.2 | 3.4 | 4.1 | 4.2 | 4.0 |
| **Ranking** | **6** | **5** | **4** | **2** | **1** | **3** |

*Assumes centrifuge test on assemblies

** Assumes spacecraft random vibration instead of sine vibration

Sine test effectiveness ratings:

- 5- high effectiveness
- 4- good effectiveness
- 3- moderate effectiveness
- 2- limited effectiveness
- 1- ineffective